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14. ABSTRACT

We examine the source regions of the largest prompt solar energetic particle (SEP) events (J_{proton}[>10 MeV] >100 pr/cm^2/s/sr) occurring between 1992 and 2002. We find that the 25 such events originated in a broad spectrum of solar regions, ranging from large complex active regions with delta sunspot groups (e.g., 30 October 1992) to a very weak active region in which the major feature was a large filament that erupted to produce the SEP event (12 September 2000). Most source regions are less than two rotation old. In terms of recent work to identify two types of large SEP events on the basis of composition, spectra, and charge state, we find that large complex active regions can give rise to both types, whereas simple and magnetically weak regions are preferentially linked to one type.

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Source Regions of Major Solar Energetic Particle Events

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Abstract

We examine the source regions of the largest prompt solar energetic particle (SEP) events (J_{proton}[>10 MeV] >100 pr/cm^2/s/sr) occurring between 1992 and 2002. We find that the 25 such events originated in a broad spectrum of solar regions, ranging from large complex active regions with delta sunspot groups (e.g., 30 October 1992) to a very weak active region in which the major feature was a large filament that erupted to produce the SEP event (12 September 2000). Most source regions are less than two rotation old. In terms of recent work to identify two types of large SEP events on the basis of composition, spectra, and charge state, we find that large complex active regions can give rise to both types, whereas simple and magnetically weak regions are preferentially linked to one type.

1. Introduction

It is widely accepted that shocks driven by fast coronal mass ejections (CMEs) are responsible for large ("gradual") SEP events [4]. In this study, we examine solar source regions of SEP-producing CMEs. Earlier researchers found that big SEP events originated in large complex sunspot groups [5], to the extent that the existence of such active regions could be used as a basis for SEP event prediction. Here we re-examine this earlier finding, using modern data to confidently identify the source regions.

2. Analysis

We began with the SEP event list maintained by NOAA, which includes all SEP events for which J_{proton}[>10 MeV] >10 PFU (= pr/cm^2/s/sr). We focused on those events whose fluxes increased over 100 PFU within ~12 hours from event onset. A prompt rise ensures unambiguous determination of the associated solar event. Twenty five such events were observed in 1992-2002.

We first studied the general properties of the source regions, such as location, age, sunspot area, and sunspot class(Figure 1). Four of the events occurred

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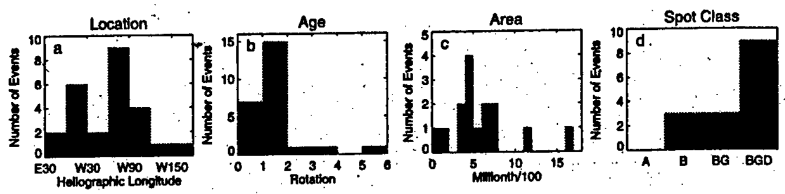

Fig. 1. Characteristics of the active regions linked to major SEP events

at or behind the west limb and no flare was reported. For these events, we used coronagraph observations and active region histories to identify the solar source. The longitudes of the source regions (Figure 1a) are broadly distributed. Source regions of these large SEP events were usually less than two rotations old (Figure 1b), as determined primarily from SOHO/MDI magnetograms We regarded regions on successive rotations to be the same if differences in their central positions in both longitude and latitude were less than 5 degrees.

A total of 15 SEP events are found to be associated with source regions within 75 degrees of longitude (thus without serious foreshortening), and the distribution of their areas is given in Figure 1c. Although most areas are within 300–800 millionths of the solar disk, there are certainly giant regions associated with large SEP events. At the other extreme, one source region (for the 12 September 2000 event) had sunspots that covered only 10 millionths of a hemisphere while another (for 8 November 2000) involved three small active regions each with sunspot areas of only $\sim$100 millionths or less. For the 15 "active regions" within 75 degrees from disk center, there is a preference for γ or δ magnetic field configurations, but both the 12 September 2000 and 8 November 2000 source regions had simpler β configurations.

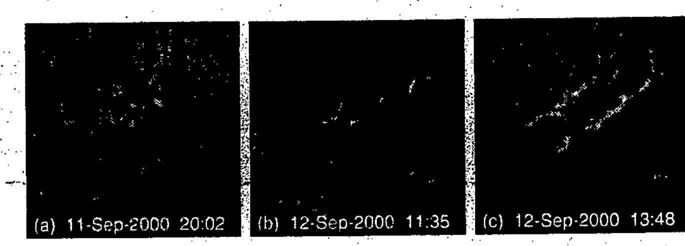

Fig. 2. Filament eruption associated with the SEP event on 12 September 2000. Panels (a) and (c) show Hα images before and after the eruption, while (b) shows an EUV image that captured the filament during the eruption. This eruption resulted in an M1 flare, but there were no large spots in the region. The field of view is (700 arcsec)^2. North is up and west is to the right.

Figure 2 shows Hα and EUV images of the nearly spotless region (on its second rotation) that was associated with the 12 September 2000 SEP event. They clearly show that it was a filament eruption. In fact, this is a rare case where we were able to trace the eruption in images from SOHO/EIT (with a cadence of only 12 minutes). Examples of SEP events associated with filament eruptions have been shown before [2], but the 12 September event is more than an order of magnitude more intense than previous cases.

Turning to complex active regions, the associated flares may take different forms. This is illustrated in Figure 3, which shows MDI continuum images of two complex active regions that produced large flares/CMEs associated with large SEP events. Superposed contour maps of hard X-ray (53-93 keV) images from *Yohkoh*/HXT take quite different forms in the two regions. For the 6 November 1997 flare, hard X-ray emission is concentrated around emerging sunspots that were a small part of the entire region while for the 14 July 2000 flare, the hard X-ray sources occupy large areas of the active region. These differences may be related to SEP characteristics as discussed below.

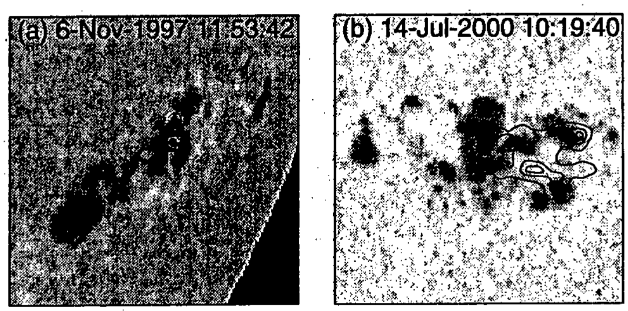

Fig. 3. MDI continuum images for two large and complex active regions from which fast CMEs started, producing large SEP events. Superposed (in white in (a) and black in (b)) are contours of hard X-ray (53–93 keV) sources at 20%,50% and 80% contours. The field of view is (220 arcsec)^2.

3. Discussion

We first point out that large complex sunspot groups are not a necessary condition for the occurrence of large >10 MeV protons events, despite a certain correlation between them. An extreme case is the 12 September 2000 event which originated in a disappearing filament in an active region nearly devoid of spots. Although long-term evolution of active regions [1] shows that the period of CME activity can outlive that of flare activity, we note that the three cases of SEP source regions with unimpressive sunspots in our sample were only two rotations old. In general, the large SEP events in our sample occurred early in the lifetimes of the associated regions, most commonly on the second rotation.

In a recent work using a small number of examples, we have shown that the way flare ejecta are first observed may be correlated with SEP properties [3]. The difference is whether the main ejection (presumably directly related to the CME) is preceded by a gradual motion on the scale comparable to the whole active region or not. Those flare ejections preceded by gradual large-scale motions tend to be associated with SEP events which have: energy spectra for oxygen above ~1 MeV/nuc that are power-laws modulated by an exponential rollover; Fe/O ratios above ~1 MeV/nucleon that decrease with increasing energy, falling to highly-suppressed levels relative to the corona and solar wind; and low Fe charge states (~10–14). Flares with ejections that start explosively during the impulsive phase appear to correspond to SEP events that have: oxygen spectra above a few MeV/nuc that are pure power-laws; Fe/O ratios that increase with energy above a few MeV/nuc and reach values that are enhanced with respect to the corona and solar wind; and high Fe charge states (~20).

Since 14 July 2000 is an example of the first type of SEP event and 6 November 1997 is an example of the second, it appears that the hard X-ray image morphology shown in Figure 3 may provide similar diagnostic information. Compact sources are seen for flares without pre-ejection motions, and extended sources (sometimes not well represented in the indirect imaging) may indicate flare energy release is part of the large-scale (CME) process. Analysis of more SEP-associated events with RHESSI will clarify how such difference in hard X-ray sources may be related to the observed SEP properties described above.

Note that both the 14 July 2000 and 6 November 1997 events, exhibiting quite different SEP characteristics, arose from large magnetically complex sunspot groups. At the other end of the spectrum of SEP source regions, there appears to be a preference for weak and magnetically simple sunspot groups to produce events with low Fe charge states and spectra with exponential rollovers (e.g., 20 April 1998 and 8 November 2000), although the SEP characteristics for the disappearing filament event on 12 September 2000 event do not fit cleanly into either of the types described above.

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